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ABSTRACT

A study was undertaken to determine aspects of gender-related differences in mathematics achievement among 10th graders (n=253). More specifically, the following aspects were assessed: (1) gender-related differences and similarities on specific process-, content-, and micro-component aspects; (2) stability of the patterns of differences and similarities over a 2-year period; (3) similarity across genders of cognitive representations of reading and mathematics; and (4) similarity across genders in size and pattern of predictors of performance on mathematical processes. Teachers of English and mathematics administered, respectively, the Reading Comprehension and Mathematics tests of the Canadian Tests of Basic Skills, Form 5, to 10th graders in a city high school in May, 1987 and 1988. Fifty-eight males and 66 females were tested in 1987, and 57 males and 72 females were tested in 1988. Items of each test were grouped into content by skill micro-components, and raw scores for each micro-component were determined. Content and process component raw scores for each test were computed. Factor analysis, regression analysis, multivariate analysis, and analysis of variance were conducted. Factor matrices for males and females were very similar. Significant differences were found in favor of males on all three process components, on all but two content components, and on five of the micro-components. Patterns of observed differences were similar for the two yearly test administrations. Six data tables are included. (TJH)

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Components of Sex Differences in Mathematics Achievement

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Abstract

The study addressed four specific objectives. 1) On what specific process-, content-, and micro-components are males and females similar and different? 2) Are the patterns of these similarities and differences stable over a two year period? 3) Are the cognitive representations of reading and mathematics micro-components similar for males and females? 4) Are the predictors of performance on mathematical processes similar in size and pattern for males and females?

Teachers of English and mathematics administered, respectively, the Reading Comprehension and Mathematics tests of the CTBS, Form 5, to the grade 10 students in a city high school in May, 1987 and 1988. A total of 250 students were tested.

Items of each test were grouped into content by skill micro-components and raw scores for each micro-component were determined. Also, content and process component raw scores for each test were computed. Factor analysis, regression analysis, and Manova and Anova procedures were used for data analysis.

Factor matrices for males and females were highly similar. While the pattern of prediction for males' and females' data for the Computation and Concepts components were similar, such was not the case for the Problem Solving. Also, significant differences in favor of males were found on all three process components, on all except two content

components, and on five of the micro-components, and patterns of observed differences were similar for two years. Results are related to the emerging theory of sex differences in mathematics and specific research and practical implications are discussed.

Components of Sex Differences in Mathematics Achievement

Psychologists have attempted to explain sex differences in mathematics achievement on the basis of underlying ability (Benbow & Stanley, 1980; 1981; 1982) and differential course taking (Fennema & Sherman, 1977). Stylistic information processing, as an alternative explanation to sex differences, was proposed by Dinnel and Glover (1987). Assumed, in this explanation, are the well known concepts of storage and retrieval capacity and strategy, knowledge representation, planning, and execution. However, other than the research involving experts and novices, not much systematic work explaining sex differences has been reported. Nevertheless, a number of studies have reported achievement differences in mathematics (e.g., Fox, Brody, & Tobin, 1980; Randhawa, 1988; Randhawa & Hunt, 1987; Benbow & Stanley, 1980; 1981; 1982).

Particularly, Randhawa and associates demonstrated that sex differences in mathematics achievement are limited to a few micro-components. However, their and others' research does not directly address these questions: 1) Are the patterns of performance similarities and differences of males and females in mathematics components stable over different cohorts from similar contextual backgrounds? 2) Are the cognitive representations of reading and mathematics components of males and females similar over cohorts? and 3) Are the predictors of mathematics process components for males and females similar in size and pattern? Therefore, it

is primarily for assessing these questions that the present study is focussed. The present study involves a city school attended by students primarily from the circumscribed attendance district. Therefore, it can be assumed that both males and females represent similar contextual (socioeconomic, teachers, learning resources, and community support mechanisms) backgrounds. Furthermore, data for the present study cover two grade ten cohorts.

It is still not clear whether sex-related differences in mathematics achievement are due to differential course taking, innate ability differences, or autonomous learning behavior. Experimental research to untangle the associated variables, which might account for sex-related differences, is difficult, if not impossible. The only alternative is quasi-experimental research in which differential course taking and other contextual variables are either controlled or are assumed to be similar in terms of their impact. The present study assumes the latter and has the following specific objectives:

1. On what specific process components, content components, and micro-components in mathematics are males and females similar and different?

2. Are the patterns of similarities and differences in performance in mathematics components stable over a two year period?

3. Are the cognitive representations of reading and mathematics micro-components similar for males and females?

4. Are the predictors of performance in mathematical processes similar in size and pattern for males and females?

Method

Procedure. In May, 1987 and 1988, grade 10 students were administered the Reading Comprehension and Mathematics tests of the Canadian Tests of Basic Skills (CTBS), Form 5, Level 16 (King, 1982). The Reading Comprehension test was administered by the teachers of English in their respective grade 10 classes. Similarly, the Mathematics test was administered by the mathematics teachers. Standard instructions and time limits for these tests were strictly followed during the testing sessions.

Score Components. Following the content and skill (process) classification tables, items of each test were grouped into content by skill components. The Reading Comprehension (R) test consists of two content categories, textbook and everyday, and three skill categories, fact, inference, and generalization. The Mathematics (M) test consists of seven content categories, operations, equivalent forms and order, common applications, algebra, geometry and measurement, statistics, graphs, and tables, and basic mathematical principles. The skill categories of this test are computation, concepts, and problem solving.

The number of items correctly answered in each micro-component category of the two tests was determined. Also, content and process component scores for each test were obtained. The number of items, the total possible score,

by content and process classification of the R and the M tests are given in Tables 1 and 2, respectively. These tables also provide the reliabilities of the items in each micro-component, process component, content component, and the total test for the grade 10 students in the two cohorts.

Insert Tables 1 and 2 about here.

Subjects. Participants in the study were 58 males and 66 females, tested in 1987, and 57 males and 72 females who were tested in 1988. These students were in grade 10 at a city high school in a mid-western Canadian province. The high school is in a mixed neighborhood in terms of socioeconomic classification of families and is in a city of 180,000 residents.

Analysis

In order to understand the similarities and differences between males and females, three types of analyses were performed; factor analysis, regression, and multivariate and univariate analysis of variance. Factor analysis was done for the intercorrelation matrices of males', females', and total group's micro-component scores on Reading Comprehension and Mathematics tests. After the iterative principal components analysis, the obtained factor matrices were rotated to make the three matrices as similar as possible using the Procrustes solution.

Regression analysis was performed using each of the

three process components as a dependent variable and Reading Comprehension and the other two process components as predictor variables for males and females data separately.

Three sets of multivariate and univariate analyses of variance were performed using the micro-components, content components, and process components, respectively, as dependent variables and sex and year as independent variables.

Results

Cognitive Structure

The rotated factor matrices for males and females indicated the similarities of underlying cognitive representation, for in each case, the two factors, Reading Processes and Mathematics Processes, were highly similar (see Table 3). The congruence coefficients were in the 90's.

Insert Table 3 about here.

Regression

The results of regression analysis for the males' and females' data are given in Table 4. For the males, Computation was significantly jointly predicted by Concepts and Problem Solving processes (R^2 = .52). On the other hand, significant joint predictors for Computation for the females were Problem Solving and Concepts (R^2 = .46). The size and pattern of prediction for males and females for the Computation component apparently are similar.

Insert Table 4 about here.

For the prediction of Concepts for the males, all three predictors entered the prediction equation with R^2 = .69. Similarly, for the females, the three predictors predicted 64%. Hence, the pattern of prediction of conceptual processes appears to be similar for males and females.

Three predictors, Concepts, Reading Comprehension, and Computation predicted 63% of the variance in Problem Solving for males. On the other hand, Concepts and Computation were the only two variables that entered the regression equation and accounted for 60% of the variance in Problem Solving for females. Comparison of these results suggests that for the Problem Solving processes, males and females rely on different component processes. Females, it seems, do not generally take advantage of the reading skills in solving mathematical problems. Is it that females tend to decontextualize the problems and do not see the need to deploy optimally reading competence? In the subject cohorts in the present study, males and females seem to have similar overall reading comprehension means. Or, is it that the edge males have over females in the other two mathematical components confounds the problem? These questions need to be addressed in the future.

Manova and Anova

Total test scores. The two total test scores of the

Reading Comprehension and Mathematics tests were used in the Sex X Year design as the vector of dependent variables. The means of the main effects are given in Table 5. The significant multivariate F-test for the Sex main effect indicated that the vector of means for the males and females were unequal [F (2, 248) = 3.25, $p \leq 0.05$]. The corresponding univariate test indicated that males' mean on the Mathematics test was significantly greater than that of the females' [F (1, 249) = 3.86, $p \leq 0.05$]. The null hypothesis regarding the equality of means on the Reading Comprehension test was not rejected. The multivariate tests of the Year main effect and the interaction term were not significant.

Insert Table 5 about here.

Process components. Subscores on the three Mathematics Process Components, Mathematics Computation, Concepts, and Problem Solving, were used in the same design as above. Means of the main effects are reported in Table 5. The multivariate Sex main effect was significant [F (3, 247) = 4.01, $p \leq 0.01$] and the corresponding univariate effects were significant for all three components ($p \leq 0.05$). An examination of means in Table 5 indicates that in each of these components males' mean was higher than that of the females' (see Table 5).

Incidentally, it was observed that the multivariate Year

main effect was also significant [F (3, 247) = 4.55, $p \leq$ 0.05] and the corresponding univariate effects for Concepts and Problem Solving were also significant at the 0.05 level. This suggests that the 1988 cohort achieved higher than the 1987 cohort on these two components. It is not clear how to explain this finding. However, conjecturally it could be that this cohort either had a better knowledge base or the teachers did a better job with them or that there was some selective process that might have been instrumental for these differences.

Content components. In the same design, seven Content Components were used as dependent variables. Again, both the Sex [F (7,243) = 2.47, $p \leq 0.05$] and Year [F (7, 243) = 3.22, $p \leq 0.05$] multivariate main effects were significant. The corresponding univariate Year effects were significant for Common Applications; Algebra; Statistics, Graphs, and Tables; and Basic Mathematical Principles such that the means of the 1988 students were greater than those for the 1987 students in each case. On the other hand, the univariate Sex effects were reliable for Equivalent Forms and Order; Common Applications; Algebra; Geometry and Measurement; and Basic Mathematics Principles. On these significant Content Components, males had higher means than females (see Table 5). As there was no significant interaction between Sex and Year independent variables, it would suggest that the pattern of differences observed on each of these variables individually is consistent over the categories of the other.

Micro-components. Eleven Micro-components were the dependent variables for this analysis. The results indicated that the vectors of means of males and females were significantly different [F (11,239)= 1.86, $p \leq 0.05$]. Corresponding univariate effects of the Sex factor were significant for Computation involving Operations, Geometry, and Measurement; Problem Solving involving Common Applications; Computation of Common Applications and Algebra content; Geometry and Measurement Concepts; and Basic Mathematical Principles Concepts. An examination of the means given in Table 6 pinpoints, at the microscopic level, the Content and the corresponding Processes where females have not achieved as well as males.

Insert Table 5 about here.

The multivariate Year effect was significant [F (11,239) = 2.04, $p \leq 0.05$] which suggests that the vectors of means for the 1987 and 1988 students were different. But, the univariate effects of Year were significant for Problem Solving involving Common Applications; Common Applications and Algebra Concepts; Problem Solving involving Algebra, Equivalent Forms and Order content; Statistics, Graphs, and Tables Concepts; and Basic Mathematical Principles Concepts. Again, as expected, the 1987 group did not perform as well in these Micro-components as the 1988 group. Because, the Year X Sex interaction was not significant, the achievement

differences of males and females can be generalized to the two years investigated.

Discussion and Conclusion

The general cognitive structure of males and females for Reading Comprehension and Mathematics is similar. Moreover, the size and pattern of regression of Computation and Concepts for both males and females are identical. Nevertheless, there are differences in the manner in which the Problem Solving component is dependent. Males seem to rely directly on Reading Comprehension for these processes whereas Reading Comprehension for females serves indirectly through Computation and Conceptual processes. These findings are further amplified in the three multivariate analysis of variance designs.

Items comprising Computation were combined into two micro-components; males were found to have a higher mean than females on Computation and on each of the micro-components. This suggests that there is a generalized difference in computational processes which favor males in spite of similar mathematical experience and contextual background variables. Previous research, involving large representative grade 10 samples (Randhawa & Hunt, 1987; Randhawa, 1988), did not find significant Sex differences on Computation. The Randhawa and Hunt (1987) study had employed the STEP tests and Randhawa (1988), on the other hand, used the same mathematics test as in the present study. The STEP Mathematics tests do not have micro-component and componential classification of items

similar to that of the CTBS tests. Therefore, a direct comparison of results with this study is not possible. However, Randhawa's (1988) analysis of the mathematics micro-components indicated that males were significantly higher than females on a cluster of four items on Computation other than the micro-component of five items from the Operations content. At least, there is a partial support of the results from this source.

On Concepts process component again males had a significantly higher mean than that of females. However, only on two of the five micro-components involving mathematical concepts, Basic Mathematical Principles, and Geometry and Measurement, did this male advantage reach significance. Hence, this generalization can be applied to 11 of the 20 items which are clustered into two micro-components. Randhawa and Hunt (1987) reported that the mean, adjusted for general intelligence, of males on the STEP Math Concepts test was significantly higher than that of females. In that study, they also reported equivocal differences on micro-components, on one males were higher and on two females. On the other hand, Randhawa (1987) did not find reliable sex differences either on the CTBS Concepts components or on any of the micro-components. It may well be that, in these two larger studies, differences in contextual and other factors of the classes involved might have masked the differences found in our present study.

On the Problem Solving component, our results favoring

males have also been reported in many previous studies (see Benbow & Stanley, 1980; 1981; 1982; Fox et al., 1980; Randhawa & Hunt, 1987; Randhawa, 1988). Also, on one of the micro-components with the largest number of items (9), Problem Solving involving Common Applications, males' mean was significantly higher than that of females'. Other three micro-components consisting of three or four items show the same trend but, perhaps due to the low reliability, did not reach significance. In order to determine conclusively whether sex differences on problem solving in mathematics are generalizable across all micro-components of a specific domain and grade level it is necessary that the number of items on each micro-component be sufficiently large to ensure reasonable reliability of the measurement. Future research directed on this aspect while at the same time controlling other confounding variables has the potential of enhancing understanding of this issue. There are indications from regression analysis results that males and females while relying on mathematics knowledge base for solving problems in mathematical content either deploy other knowledge strategically or not which eventually makes a difference in the outcomes. Again, more definitive and experimental research is needed to determine the course of interplay of knowledge utilization strategies.

As it is evident from this and earlier research that cognitive representation of mathematical and reading micro-components is invariant for sex, there must be

meta-cognitive and autonomous processes which mediate the sex differences. Hints and suggestions are emerging but definitive and direct evidence is lacking on how these processes differentially predict problem solving outcomes and processes. Our current research based on direct interface with learning and instructional situations in mathematics classes holds promise for addressing these baffling questions.

A simplistic explanation of sex differences in mathematics achievement from this particular research is that males have acquired cumulatively a generally enriched understanding of mathematical process skills by grade ten and that smaller and nonsignificant advantages observed at grade four and grade seven levels have given rise to discernible and reliable differences by high school and beyond. Cumulative advantage or deficit as a hypothesis for sex differences has already been used as a plausible reason for sociocultural advantages and disadvantages (see de Lacey, Barlow, & Ronan, 1985).

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Table 1

Number of Items by Content and Process Classification of the CTBS, Form 5, Level 16, Reading Comprehension Test

Content	Process			
	Fact	Inference	Generalization	Total
Textbook	12 (72)	12 (61)	9 (41)	33 (82)
Everyday	11 (68)	11 (62)	7 (55)	29 (83)
Total	23 (81)	23 (78)	16 (61)	62 (90)

[a]These are KR-20 reliabilities rounded off to two decimal places and the decimal points are omitted.

Table 2

Number of Items by Content and Process Classification of the CTBS, Form 5, Level 16, Mathematics Test

Content	Process			
	Computation	Concepts	Problem Solving	Total
1. Operations	5^1 (51)	0	0	5 (44)
2. Equivalent Forms and Order	0	4 (49)	1^4 (20)	5 (51)
3. Common Applications	1^2 (35)	1^3 (41)	9 (61)	11 (69)
4. Algebra	2^2	1^3	2^4	5 (42)
5. Geometry & Measurement	1^1	4 (37)	3 (38)	8 (53)
6. Statistics, Graphs & Tables	0	3 (42)	4 (27)	7 (51)
7. Basic Mathematical Principles	0	7	0	7 (47)
Total	9 (62)	20 (79)	19 (73)	48 (89)

Note: The micro-components with the same subscripts were combined both for reliability and Manova analyses. The figures in parentheses are the KR-20 reliability coefficients with decimals omitted.

Table 3
Procrustes Rotated Factor Pattern Matrix for Males which is Congruent to the Oblimin Rotated Factor Pattern Matrix for Females

Variable	Factor Pattern					
	Females (N=129)			Males (N=124)		
	F1	F2	h^2	F1	F2	h^2
1. Textbook Fact	08	80	72	17	66	60
2. Textbook Inference	15	74	70	-13	91	75
3. Textbook General	-11	66	37	08	63	47
4. Everyday Fact	12	66	54	23	69	71
5. Everyday Inference	21	73	74	-11	86	67
6. Everyday General	16	63	53	33	49	51
7. Operations Comp.	47	25	41	44	31	43
8. Equivalent Forms & Order Concepts	55	16	43	63	24	60
9. Equivalent Forms & Order Problem Solving	30	-12	07	41	-11	12
10. Common Applications Computation	37	-01	13	56	-03	28
11. Common Applications Concepts	39	32	38	35	34	36
12. Common Applications Problem Solving	51	31	53	60	30	62
13. Algebra Computation	48	19	37	45	-07	17
14. Algebra Concepts	29	08	12	52	10	32
15. Algebra Problem Solving	36	19	25	30	17	17
16. Geometry & Measurement Computation	-00	25	06	35	22	25
17. Geometry & Measurement Concepts	52	-03	26	53	18	41
18. Geometry & Measurement Problem Solving	55	08	36	59	06	37
19. Statistics, Graphs, & Tables Concepts	41	33	42	50	22	41
20. Statistics, Graphs, & Tables Problem Solving	54	04	32	31	29	28
21. Basic Mathematical Principles Concepts	53	27	51	63	13	47

[a] values rounded off to two decimal places and the decimal is omitted.

Table 4

Results of Regression Analysis for the Males' and Females' Data

Group	Dependent Variable	Step-Wise Independent Variable Entered	Obtained R^2
Female	Math Computation	Math Problem Solving	.41
		Math Concepts	.46
	Math Concepts	Math Problem Solving	.55
		Reading Comprehension	.61
		Math Computation	.64
	Math Problem Solving	Math Concepts	.55
		Math Computation	.60
Male	Math Computation	Math Problem Solving	.52
		Math Concepts	.49
	Math Concepts	Math Problem Solving	.58
		Reading Comprehension	.69
		Math Computation	.66
	Math Problem	Math Concepts	.58
		Reading Comprehension	.62
		Math Computation	.63

Table 5
Means for Reading and Mathematics Total Scores, Mathematics Process Component Scores and Mathematics Content Component Scores by Sex and Year

Variable Category	Variable	Sex		Year	
		Males	Females	1987	1988
Total Score	Reading Comprehension	43.14	43.33	42.40	44.06
	Mathematics	30.27*	27.96	27.79	30.18*
Process Component	Math Computation	6.10	5.41*	5.60	5.84
	Math Concepts	12.61	11.39*	11.13	12.73*
	Math Problem Solving	11.73	10.26*	10.27	11.56*
Content Component	Operations	3.50	3.25	3.29	3.43
	Equivalent Forms & Order	2.88	2.52*	2.52	2.84
	Common Applications	7.52	6.42*	6.56	7.26*
	Algebra	3.20	2.85*	2.70	3.30*
	Geometry & Measurement	4.48	3.83*	4.00	4.25
	Statistics,Graphs & Tables	4.43	4.22	4.07	4.55*
	Basic Math Principles	4.43	3.97*	3.85	4.50*

*Indicated univariate main effects are significant at the 0.05 level.

Table 6
Means for Micro-Component Scores by Sex and Year

Variable	Sex		Year	
	Males	Females	1987	1988
Operations, Geometry & Measurement Comp.	3.84	3.48*	3.61	3.67
Equivalent Forms & Order Concepts	2.30	2.04	2.02	2.29
Common Applications Problem Solving	6.24	5.33*	5.44	6.05*
Common Applications Algebra Comp.	2.25	1.93*	1.98	2.17
Common Applications Algebra Concepts	1.28	1.12	1.07	1.30*
Equivalent Forms & Order Algebra Problem Solving	1.53	1.37	1.28	1.60*
Geometry & Measurement Concepts	2.32	2.01*	2.08	2.22
Geometry & Measurement Problem Solving	1.81	1.59	1.60	1.78
Statistics, Graphs & Tables Concepts	2.28	2.26	2.11	2.42*
Statistics, Graphs Tables Problem Solving	2.15	1.96	1.96	2.13
Basic Mathematical Principles Concepts	4.43	3.97*	3.85	4.50*

*Indicated univariate main effects are significant at the 0.05 level.